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Effect of conservation tillage on crop productivity and nitrogen use efficiency

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ABSTRACT

The hypothesis that the optimal nitrogen rate for crop yield and nitrogen use efficiency (NUE) are affected by tillage treatment, crop type and soil properties (type) was evaluated by an experiment which include five different tillage treatments (CT-conventional, SS-subsoiling, CH-chiselling, DH-disk-harrowing and NT-no-till), three levels of nitrogen rates (N1-reduced, N2-optimal and N3-luxury), on two different soil types (Stagnosol and Gleysol) and with two different crops (maize and winter wheat). Soil and plant samples were taken from the first and second year in the second four-year crop rotation cycle. The highest value of soil compaction (ρ_b-bulk density and PD-packing density) as well as the lowest soil total porosity (P) was found, on average for all tillage treatments, on Gleysol in both experimental year in the root zone (20–40 cm). At all depths the highest values of ρ_b and PD were recorded for DH treatment on Gleysol and for soil porosity for NT treatment on Stagnosol. Grain yields, biomass, and harvest index of maize and winter wheat on both soil type respond positively to conservation tillage treatment, but with different significations. Soil cover crop residues were significantly affected by soil treatment and nitrogen fertilization ($P < 0.01$), and decreasing in the following order: NT > CH > SS > DH > CT on both soil types. The average NUE in general decreased successively under N1, N2 and N3 with respective NUEs on Stagnosol 58.5, 49.5 and 36.0 kg kg^{-1} for maize and 59.9, 45.3 and 35.9 kg kg^{-1} for winter wheat. Corresponding values on Gleysol were 78.5, 69.4, 52.0 kg kg^{-1} and 46.3, 51.3, 44.0 kg kg^{-1}. The grain and biomass of winter wheat increased from N1 to N2, whereas from N2 to N3 they decreased, increased or remained almost the same depending on the tillage system and soil type. The effect of all the investigated tillage treatments on NUE and crop yield was variable depending on particular tillage system, crop type and soil type. The results indicate that, from the NUE and crop yield viewpoints, the N2 and N3 nitrogen rates are respectively most and least suitable on both soil types, depending on soil treatment. Irrespective of the nitrogen application rate and tillage treatments, the NUEs were the most comparable treatments higher in the more productive Gleysol (32.7–92.5 kg kg^{-1}) than in Stagnosol (26.4-76.7 kg kg^{-1}).

1. Introduction

Conservation Agriculture (CA) with its own three linked basic principles (minimal/optimal/adaptable sets of soil tillage measures, permanent soil cover with crops and/or crop residues and crop rotation), (FAO, 2015) is a sustainable approach in crop production, which is universally applicable to all agroecological areas (Friedrich et al., 2012; Ceglar et al., 2018), and improves soil quality and optimizes crop yields (Hobbs, 2007; Hobbs et al., 2008; Jug et al., 2018). CA has a positive influence on soil properties and processes relative to conventional agriculture (Palm et al., 2014). The change in land-use from natural forest or perennial grasslands to cultivated croplands accounts for reduced soil organic carbon, nitrogen contents and biodiversity (Murty et al., 2002; EASAC, 2018). To alleviate the negative effects of conservation tillage based on no-till with soil surface covered by crop residues (at least 30% of the soil surface), reduced non-inversion tillage systems retaining crop residues near the soil surface along with diversified crop rotation are increasingly adopted (Davies and Finney, 2002; IPCC, 2000). Some research has shown that yield under conservation vs. conventional tillage was comparable or higher

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(Nyakatawa et al., 2000), or lower (Schwab et al., 2002) depending on the agroecological conditions. However, decreased fuel and energy inputs, improved carbon sequestration (Bolinder et al., 2018), reduction in soil erosion and evaporation, and presence of the crop residues within shallow depth of soil (Vogeler et al., 2009; Khaledian et al., 2010) under reduced or conservation tillage will improve soil quality, at first to increase humus content, sustaining agricultural production and contributing to the protection of the atmosphere (Hatano and Lipiec, 2004).

The introduction of soil to agricultural production caused a significant decline in soil functions (Günal et al., 2015), especially soil physical quality, occurring worldwide (Arshad and Martin, 2002), which influenced yield negatively (Gomiero, 2016). Soil management has an important effect on soil properties and crop productivity (Hatfield et al., 2001). According to Gal et al. (2007); Thomas et al. (2007) and D'Haene et al. (2008), the effect of tillage and crop residue mulch on soil bulk density is mainly limited to the top 20 cm of soil. Some studies (Fabrizzi et al., 2005; Taser and Metinoglu, 2005; Gathala et al., 2011; Salem et al., 2015; Jat et al., 2017) have shown that conservation tillage practices with partial crop residue cover removal, increased soil bulk density on surface soil compared to conventional tillage practices. Major threats to soil in Europe are clearly identified by the European Environment Agency (COM, 2002). One of them is soil compaction, whose intensity is estimated through soil bulk density, packing density and total porosity. Different parameters can be used in the evaluation of soil compaction (Kaufmann et al., 2010), whereby some researchers prefer bulk density (Campbell, 1994; Hakansson and Lipiec, 2000), total porosity (Lampurlanés and Cantero-Martínez, 2003) or packing density (Jones et al., 2003). Soane and van Ouwerkerk (1994) defined soil compaction as "... a process of densification in which porosity and permeability are reduced, strength is increased and many changes are induced in the soil fabric and in various behaviour characteristics", and it is increasingly becoming a serious degradation process (Khan et al., 2012). Soil compaction directly affects the physical (Håkansson, 1990) and indirectly the chemical and biological soil properties, plant productivity (Reintam et al., 2009) and yields (Çelik, 2011). The effect of soil compaction is more expressed in wetter soils, where it results in the creation of compacted deep layers, which leads to a decrease in plant productivity (Reintam et al., 2009) and yields (Çelik, 2011). A more deleterious effect of compacted layers is pronounced on root elongation and root mass (Khan et al., 2012), because plant roots cannot penetrate compacted layers, which reduces crop growth (Lipiec and Hatano, 2003).

An important issue related to tillage methods is crop nutrient economy, especially of mineral nitrogen, the production of which requires high fossil energy inputs (Hirel et al., 2011). Deficiency of soil nutrients, especially nitrogen, is one of the major yields limiting factors for cereals (McDonald, 1992), and Keeney (1982) hypothesized that the application efficiency of N fertilizer can be enhanced by synchronizing fertilizer application with plant uptake needs. Conservation soil tillage has effects on soil physical properties (Czyż and Dexter, 2008), and nitrogen management can be affected by the changes in tillage practices (Torbert et al., 2001). Soil moisture, temperature and soil nitrogen dynamics are strongly influenced by soil tillage systems (Nadelhoffer et al., 1991; Torbert and Wood, 1992). Due to the slower plant rests humification, when soil mixing by cultivation is limited, the use of conservation tillage can increase short-term nitrogen immobilization (Gilliam and Hoyt, 1987; Wood and Edwards, 1992). An appropriate nitrogen management regime in combination with a proper tillage system is expected to sustain soil fertility and productivity while increasing yields. It is known that the optimal fertilizer management practices, including soil tillage (Van Den Bossche et al., 2009) and crop residue management can decrease nitrate leaching losses from fertilized fields (Bakht et al., 2009) while sustaining crop yield. Some studies indicate that in intensive crop production systems (Hodge et al., 2000; Asghari and Cavagnaro, 2011) more than 50% of the N applied is not used by the crop and is lost by leaching or nitrous oxide emission (Hatano and Lipiec, 2004) generating environmental pollution. The inefficient wasteful use of nitrogen in crop production can be supported by data indicating that the quantity of mineral N fertilizers used in croplands during more than 40 years increased by 7.4 times, while the yield increased by just 2.4 times (Tilman et al., 2002). Therefore, the optimization of nitrogen use efficiency (NUE, that is fertilizer N recovery efficiency) under different agroecological conditions (climate hydrothermic, physical and chemical properties of soil) is an urgent need as the management strategy for increasing crop production and diminishing both N losses into the environment and farmers' input costs (Hirel et al., 2011; Habbib et al., 2016).

Many scientific papers are dealing with the possibilities of the application of different soil tillage systems and with their different multilevel effects on crop productivity at different regional, local, soil-types and field scale. Extensive research of crop growth and nutrient use in response to tillage systems was focused on the comparison of no-till vs. conventional tillage (e.g. Kelley and Sweeney, 2005; Rieger et al., 2008). However, there is little information on how other conservation tillage systems will affect crop yield and nitrogen use efficiency under the same site conditions. Therefore, the aim of this study was to determine the response of yield and NUE of winter wheat and maize under CT-conventional and four conservation tillage treatments including SS-subsoiling, CH-chiselling, DH-disk-harrowing and NT-no-till with three levels of nitrogen application in two years (2013–2014). Two experimental sites were used in this research where all tillage treatments were applied since the start of experiment in 2009. The hypothesis was that the optimum N rate for crop yield and nitrogen use efficiency is affected by tillage treatment, crop and soil type. This can contribute to a better understanding of specific relations among the investigated parameters in the given and similar agroecological conditions.

2. Material and methods

2.1. Site description and treatments

A long-term stationary field experiment was conducted since 2009 at two experimental fields on two different soil types, Stagnosol at the site Cacinci, and Gleysol at the site Magadenovac (WRB, 2015) in the Central Pannonian agricultural subregion of Croatia. The experimental fields were located in the lowlands area with a 0–1% slope (the site Cacinci, Long. 17.86336 E, Lat. 45.61316 N, Alt. 111 m and the experimental field Magadenovac, Long. 18.17254 E, Lat. 45.67046 N, Alt. 92 m), which belongs to the most crop productive agricultural region of Croatia (Bašić et al., 2007). The mean annual precipitation and temperature for both fields (30-yr average) is characterized by a wide variation from 320 to 1240 mm and 9.4–12.9 °C (Table 1). Temporal and spatial changes of the main climatic parameters follow, in most cases, the following schemes; temperatures increase from west towards the east, and from northwest to northeast, while precipitation follows inverse sequences (source Meteorological and Hydrological Service of Croatia). All climate and weather conditions in the experimental area are strongly influenced by the climate in the Pannonian agricultural region (Bašić et al., 2007) and the peri-Pannonian geographical region.

The data presented in this manuscript (soil and plant samples) was collected from the part of the second rotation of usual crop rotation in this region, in the years 2013–2014. Crop rotation includes crops in the following sequence: 2009-maize, 2010-winter wheat, 2011-oilseed rape, 2012-soybean. Maize (*Zea mays* L.) was sown in spring of 2013 (after soybean) and winter wheat (*Triticum aestivum* L.) in autumn of the same year (after maize). Five different soil tillage treatments were applied as the main experimental factor: CT-conventional, and four conservation soil tillage treatments (CST); SS-subsoiling, CH-chiselling, DH-disk-harrowing and NT-no-till. The second experimental factor was fertilization with three different nitrogen rates: N1-reduced (30% lower dosage related to the recommendation); N2-optimal (according to the

Table 1
Monthly, annual and 30-yr average precipitation (mm) and air temperature (°C) on both experimental sites (weather stations are on 1 (Cacinci) and 2 (Magadenovac) km distance).

	Site Cacinci						Site Magadenovac					
	Precipitation (mm)			Air temperature (°C)			Precipitation (mm)			Air temperature (°C)		
Month	2013	2014	1984-2013	2013	2014	1984-2013	2013	2014	1984-2013	2013	2014	1984-2013
January	87	40	56	2.2	4.3	0.6	62	52	50	2.0	3.6	0.3
February	101	65	41	2.8	5.5	1.8	112	76	39	2.8	5.2	1.8
March	97	49	54	5.1	9.6	6.3	113	25	46	4.9	9.8	6.5
April	53	98	63	13.1	12.8	11.6	46	69	57	13.3	13.2	12.0
May	80	160	75	16.5	15.4	16.3	113	139	68	17.0	15.7	17.0
June	83	64	95	19.8	20.3	19.7	54	62	86	19.9	20.4	20.3
July	28	79	69	23.3	21.8	21.8	15	82	63	23.3	22.0	22.3
August	99	135	70	22.7	20.3	21.1	73	83	66	22.8	20.4	21.8
September	143	108	77	15.7	16.4	16.4	97	119	69	15.6	16.7	16.9
October	42	116	70	13.6	11.3	11.4	29	143	61	13.3	12.9	11.6
November	102	25	74	7.6	5.8	6.0	67	24	65	7.6	7.5	5.9
December	1	78	65	2.5	1.9	1.7	1	68	56	1.8	1.9	1.3
Total annual	916	1017	809				782	942	726			
Average annual				12.1	12.1	11.2				12.0	12.0	11.5

recommendation) and N3-luxury (30% higher dosage related to the recommendation). Fertilization recommendations (based on chemical analyses of soil properties) are provided by the computer ALR expert calculator model (Vukadinović and Vukadinović, 2011). The experiment was set up as split-plot design (RCBD - randomized complete block design) with four repetitions. The size of the basic experimental plot for each individual tillage treatment was 600 m^2 and 195 m^2 for each individual fertilization treatment. Except for the soil tillage and nitrogen fertilization, all the other crop growing practices sequences: sowing, P and K fertilizing, pests' control, machinery and equipment used were identical in all the treatments.

2.2. Crop growing practices

The first experimental year presented in this manuscript (maize growing) started with the application of mineral fertilizers (autumn 2012), which was uniform across all soil tillage treatments and in distribution dynamics, but different depending on the experimental fields (Table 2). The rates of N, P and K fertilization in amount 50% of total were added prior to basic soil tillage in autumn. On NT treatment fertilizers were applied on the soil surface and without any further tillage treatment. The rest of fertilizers to total amount was applied in spring simultaneously with sowing. Nitrogen fertilizer was applied 50% in the form of urea (46% N) in autumn and 50% as CAN (27% N, calcium ammonium nitrate) in spring. Soil tillage was uniform on both experimental fields and depending on tillage treatment included as follows: CT – ploughing up to 30 cm depth, followed by disk-harrowing in autumn (1 pass), winter furrow closing with spike-tooth harrow in spring (2 passes), surface preparation with rotary harrow for sowing (1 pass); SS – subsoiling up to 35–40 cm depth, disk-harrowing in autumn (1 pass); CH – chiselling up to 25 cm depth, disk-harrowing in autumn (1 pass); DH – disk-harrowing in autumn up to 10–15 cm depth (1 pass); NT-no-till (without any soil tillage preparation). All pre-sowing soil tillage operations were applied 3–5 days prior to sowing. The maize (hybrid PR36V52, FAO 450, plant density recommendation 65 000 plants ha^{-1}) was sown at a depth of 2–3 cm, on the field Magadenovac on April 25 and on the field Cacinci on April 27. Seeding was performed by the same type of no-till planter on both fields and on all soil tillage treatment. Weeds were controlled with selective herbicides (according IUPAC: N2-tert-butyl-6-chloro-N4-ethyl-1,3,5-triazine-2,4-diamine) in post sowing pre-emergent treatment (PSPE) to the seedbed on April 28 on both fields. NT treatment was additionaly treated with non-selective herbicides three weeks before seeding in the beginning of April. Harvesting was performed on October 15 on the field Magadenovac and on October 18 on the field Cacinci, by a combine harvester after sampling all plant material (grain + stalk + leaves). The combine harvester had an integrated chopper/spreader system for improved cutting and an even distribution of crop residues.

Table 2
Fertilization dosage on experimental sites.

Fertilizer treatment (kg ha^{-1})	P_2O_5	K_2O	N1	N2	N3
<u>Site</u>	<u>Maize</u>				
Cacinci	140	150	140	200	260
Magadenovac			147	210	273
	<u>Winter wheat</u>				
Cacinci	100	110	80	115	150
Magadenovac			95	135	175

The second experimental year started with the application of mineral fertilizers and soil tillage for winter wheat (autumn 2013). Application of mineral fertilizers, just as for maize, was uniform across all soil tillage treatments and in distribution dynamics but different depending on the experimental field (Table 2). The total amount of P and K fertilizers and 50% of total N fertilizers (urea) were added prior to basic soil tillage in autumn. On NT treatment fertilizers were applied on soil surface and without any further tillage treatment. The rest of N fertilizers to the total amount were applied in two top dressing applications (CAN) evenly divided to different nitrogen rates. Soil tillage treatments include as follows: CT – ploughing up to 30 cm depth, followed by disk-harrowing (1 pass), pre-sowing surface preparation with rotary harrow + wedge ring roller (2 passes); SS – subsoiling up to 35–40 cm depth, pre-sowing surface preparation with rotary harrow + wedge ring roller (1 pass); CH – chiselling up to 25 cm depth, pre-sowing surface preparation with rotary harrow + wedge ring roller (1 pass); DH – disk-harrowing up to 10–15 cm depth (2 passes); NT-no-till (without any soil tillage preparation). Mineral fertilization and soil tillage were carried out on October 22 on the field Magadenovac and on October 25 in Cacinci. The winter wheat (cultivar Lucija - Agricultural Institute Osijek, seeding rate of 650 seeds per m^2, at the inter-row distance of 16.5 cm and depth 2–3 cm, no-till planter) was sown two days after pre-sowing preparation on both fields (October 24 and 27). Weeds were controlled with selective herbicides (chlortoluron 79.00% + triasulfuron 0.75%) in post emergent treatment (PE) on February 16 on both fields. Fungicide (epoxiconazol 125 g l^{-1} + kresoxim-methyl 125 g l^{-1}) was applied on both fields for prevention and curative treatment on April 29. After all plant material sampling (grain + stalk + leaves), winter wheat was harvested made on June 30

Table 3
Selected soil properties on experimental sites.

Site	Stagnosol (Cacinci)		Gleysol (Magadenovac)	
Soil depth (cm)	0-30	30-60	0-30	30-60
Sand (2-0.05 mm), %	15.65	18.47	9.92	10.80
Silt (0.05-0.002 mm), %	55.25	53.23	71.78	66.21
Clay (< 0.002 mm), %	29.10	28.30	18.30	23.00
Soil texture	Silty clay loam (SiCL)	Silty clay loam (SiCL)	Silty loam (SiL)	Silty loam (SiL)
Organic matter, %	2.49		1.45	
pH_{H2O}	5.09		5.29	
pH_{KCl}	4.03		4.27	
P (AL), mg kg^{-1} soil	62		172	
K (AL), mg kg^{-1} soil	127		227	
Hy, $cmol^{(+)} kg^{-1}$	2.54		4.39	

(Cacinci) and July 2 (Magadenovac) by a combine harvester with an integrated chopper/spreader system.

2.3. Soil sampling and analysis

Soil samples for basic chemical analysis (Table 3) were collected before setting up of the experiment with a soil auger from 0 to 30 cm depth. The experimental sites are treated as a homogenous area and each composite sample consisted of 20–25 individual disturbed soil samples taken with the auger. Average soil samples were air-dried, homogenized, milled and passed through a 2 mm sieve and analysed on basic soil chemical properties. Soil pH was measured electrometrically in a 1:5 (w/v) soil: water (distilled) extract (pH-H_2O) and 1 mol dm^{-3} KCl (pH-KCl). Plant available P and K were analysed using ammonium lactate acid extractant (Egner et al., 1960). Hydrolytic soil acidity (Hy) was determined by titration where we used alkaline hydrolytic salts (Ca-acetate) to exchange H^+ and Al^{3+} ions from the soil adsorption complex. Soil organic matter content was measured using modified Walkley-Black method (Bahadori and Tofighi, 2016).

Soil samples for analyses of selected physical properties (Appendix A1) were sampled from all soil tillage treatments six times per year in an interval of 30 days, starting on May 15 in 2013 and on February 15 in 2014. Sampling-day varied ± 1-3 days in 2013 and ± 2–5 days in 2014 (depending on site and weather conditions). Five undisturbed samples of 100 cm^3 were taken at three different layers (0–20, 20–40 and 40–60 cm depth). Soil texture was determined by pipette-method with wet sieving and sedimentation after dispersion with sodium pyrophosphate (ISO 11277, 2009) according USDA-NRCS (2016). Undisturbed samples were used to gravimetrically determine soil bulk density ρ_b (ISO 11272, 2004) and soil particle density, ρ_s, by pycnometer method (ISO 11508, 2004). Values for ρ_s are not presented in the paper, but were used to calculate soil porosity (P) as $(1 - \rho_b / \rho_s) \times 100$. Packing density was calculated by ρ_b and clay content as: $\rho_b + (0.009 \times \text{clay}\ \%)$, (Jones et al., 2003).

2.4. Plant material sampling and analysis

On April 28, 2013, after maize sowing and on October 29, 2013, after winter wheat sowing, soil crop residues cover were measured using the Line-transect method (Morrison et al., 1993; Laamrani et al., 2017). Plant material samples for calculation of biomass production (biological yield) for both crops were collected from all treatments 2–5 days before harvest. Biological yield is considered as the total crop biomass above ground (grain + stalk + leaves) and excluded roots. Maize plant material samples were collected as five separated samples, and each sample consisted of 20 plants collected in line and diagonally on each tillage treatment. Winter wheat plant material samples were collected using 50 cm × 50 cm frame randomly and diagonally in five repetitions on each tillage treatment. All samples (maize and winter wheat) were dried in the oven at 65 °C to constant weight to obtain dry matter weight and calculate per hectare. Grain yield was calculated from the same samples after hand harvesting and grain separation from the rest of plant material (stalk + leaves). Calculation of grain yield (t ha^{-1}) was done with grain yield moisture at 14% for maize and 12% for winter wheat. Harvest index (HI) was calculated according Wnuk et al. (2013) ((HI = grain yield/ biological yield) × 100, %). Nitrogen use efficiency (NUE) was calculated as the yield obtained per unit of mineral N fertilizer applied and expressed in kg kg^{-1} [NUE = yield (kg ha^{-1})/mineral N fertilizer (kg ha^{-1})]. The calculation was done for grain yield and biological yield of maize and winter wheat.

2.5. Data analysis

All the collected data was statistically processed by the package Statistica v.10 (StatSoft, Inc., 2011). The Pearson's linear correlation coefficients according to Mukaka (2012) and the value of correlation coefficient ranking by the Roemer-Orphal scale (± 0.00-0.30: negligible correlation, ± 0.30-0.50: low, ± 0.50-0.70: moderate, ± 0.70-0.90: high, ± 0.90-1.00: very high) according to Hinkle et al. (2003) were used to assess the relationships between the soil physical parameters (ρ_b-bulk density, PD- packing density, P-total porosity), soil depth and clay content (cfc-clay fraction content) during the vegetation periods of the study years on both experimental sites. The descriptive statistic was performed in Microsoft Excel and applied to analyse the differences in these parameter values between soil tillage treatments in both experimental years and experimental fields. The effect of soil type and tillage treatments on ρ_b, PD and P was tested by ANOVA of the split-plot design in four repetitions where soil type was main plot and tillage system was subplot. The means were compared by F-test protected LSD values calculated for $P < 0.05$. The data for ANOVA was collected before the harvest of maize (September 2013) and winter wheat, respectively (June 2014). The influence of different tillage treatments and different level of nitrogen fertilization on crop productivity parameters of maize and winter wheat was tested by ANOVA of the split-plot design, where tillage treatments were treated as the main plot, and nitrogen level as the subplot. The means were compared by F-test protected LSD values calculated for $P < 0.05$.

3. Results

3.1. Soil physical properties

Soil physical properties as parameters of soil compaction are presented in Table 4 (correlation coefficients), Tables 5 and 6, Appendix A1 (descriptive statistics) and Fig. 1 (average value for all tillage treatments and soil depths).

3.1.1. Bulk density (ρ_b)

The significant influence of soil type ($P < 0.01$) and tillage treatment ($P < 0.01$) at ρ_b at all layers was recorded during 2013 (maize crop). At depths of 0–20 cm and 20–40 cm ρ_b was higher at Gleysol, while on Stagnosol higher values were recorded at 40–60 cm (Table 5). Significantly lower (from 2.63 to 3.27%) ρ_b (comparing both soil types) was recorded on CT compared to SS, DH, CH and NT at depths of 0–20 cm. At a depth of 20–40 cm, the lowest ρ_b was recorded at DH, which was significantly lower (from 3.77 to 5.56%) compared to other tillage treatments. Soil compaction on CT treatment was significantly lower (from 1.24 to 1.85%) than SS, CH and NT among which there were no significant differences. At a depth of 40–60 cm, the largest ρ_b was recorded on DH treatment, and the lowest on NT. During 2014 (winter wheat crop), soil type significantly ($P < 0.01$) affected on ρ_b at all depths while soil tillage impact was significant ($P < 0.05$) at depths of 0–20 cm and 40–60 cm (Table 6). The significantly higher soil compactness (for 12.41% on 0–20 cm, 12.27% on 20–40 cm and 1.88%

Table 4
The Pearson's linear correlation coefficients of selected soil compaction physical parameters on experimental sites.

	Stagnosol (Cacinci)				Gleysol (Magadenovac)			
	Soil depth	ρ_b	cfc	PD	Soil depth	ρ_b	cfc	PD
CT								
ρ_b	0.655**				0.323**			
cfc	−0.866**	−0.551**			0.866**	0.191*		
PD	0.634**	0.999**	−0.522**		0.515**	0.969**	0.427**	
P	−0.749**	−0.981**	0.702**	−0.974**	NS	−0.979**	NS	−0.905**
SS								
ρ_b	0.482**				0.407**			
cfc	−0.866**	−0.476**			0.866**	0.123		
PD	0.459**	1.000**	−0.448**		0.602**	0.967**	0.370**	
P	−0.591**	−0.984**	0.623**	−0.978**	−0.214*	−0.979**	NS	−0.901**
CH								
ρ_b	0.550**				0.522**			
cfc	−0.866**	−0.552**			0.866**	0.227*		
PD	0.530**	1.000**	−0.528**		0.691**	0.971**	0.454**	
P	−0.644**	−0.986**	0.683**	−0.981**	−0.349**	−0.982**	NS	−0.912**
DH								
ρ_b	0.545**				0.244**			
cfc	−0.866**	−0.559**			0.866**	NS		
PD	0.522**	0.999**	−0.532**		0.475**	0.963**	0.196*	
P	−0.645**	−0.984**	0.697**	−0.978**	NS	−0.978**	0.265**	−0.890**
NT								
ρ_b	0.537**				0187*			
cfc	−0.866**	−0.575**			0866**	NS		
PD	0.513**	0.999**	−0.547**		0394**	0971**	NS	
P	−0.642**	−0.982**	0.717**	−0.975**	NS	−0,984**	0277**	−0,916**

CT: conventional tillage; SS: subsoiling; CH: chiselling; DH: disk-harrowing; NT: no-till; Note: ρ_b-bulk density, g cm^{-3}; cfc-clay fraction content, %; PD-packing density, g cm^{-3}; P-total porosity, %; Significance: NS, not significant; * significant at $p < 0.05$; ** significant at $p < 0.01$.

on 40–60 cm, respectively) was observed at Gleysol. At a depth of 0–20 cm the highest soil compactness was recorded on DH which was significantly higher (from 4.00–6.67%) compared to other soil tillage treatments. On CH a significantly higher ρ_b was recorded compared to CT (1.88%), SS (1.25%), DH (2.5%) and NT (1.88%) at a depth of 40–60 cm.

On the Stagnosol soil type (the experimental field Cacinci) in the top layer (0–20 cm) ρ_b on CT treatment was slightly higher (1.48 g cm^{-3}) in comparison to the mid layer (20–40 cm, 1.47 g cm^{-3}), while in all other tillage treatments ρ_b increases with increasing depth (Fig. 1). These relations are also visible through significant ($P < 0.01$) values of the Pearson's linear correlation coefficients (Table 4). Low positive correlation was detected on SS ($r = 0.48$) and moderate positive ($r = 0.54$ to $r = 0.66$) in all other tillage treatments. Low negative correlation of ρ_b and clay content were found in SS ($r=-0.47$) and moderate negative ($r=-0.55$ to -0.58) in other tillage treatments. Separation analyses of

Table 5
The effect of soil tillage on selected soil compaction physical parameters on experimental sites in 2013.

Year (2013)		ρ_b			PD			P		
Soil depth (cm)	Tt	Stag	Gley	$\bar{X}$	Stag	Gley	$\bar{X}$	Stag	Gley	$\bar{X}$
0-20	CT	1.43	1.54	1.48^b	1.69	1.80	1.74^b	44.38	40.27	42.32^a
	SS	1.50	1.53	1.52^a	1.77	1.80	1.78^a	41.49	40.33	40.91^b
	CH	1.47	1.57	1.52^a	1.73	1.83	1.78^a	42.76	38.90	40.83^b
	DH	1.48	1.58	1.53^a	1.75	1.84	1.79^a	42.29	38.72	40.50^b
	NT	1.49	1.55	1.52^a	1.76	1.82	1.79^a	41.81	39.53	40.67^b
$\bar{X}$		1.48^B	1.55^A	1.52	1.74^B	1.82^A	1.78	42.54^A	39.55^B	41.04
20-40	CT	1.50	1.67	1.59^b	1.77	1.93	1.85^b	41.47	35.00	38.24^c
	SS	1.58	1.63	1.61^a	1.84	1.89	1.87^a	38.53	36.47	37.50^b
	CH	1.57	1.67	1.62^a	1.83	1.93	1.88^a	38.92	35.02	36.97^b
	DH	1.42	1.63	1.53^c	1.69	1.89	1.79c	44.62	36.62	40.62^a
	NT	1.46	1.75	1.61^a	1.73	2.01	1.87^a	43.04	31.86	37.45^b
$\bar{X}$		1.51^B	1.67^A	1.59	1.77^B	1.93^A	1.85	41.32^A	34.99^B	38.16
40-60	CT	1.62	1.56	1.59^c	1.88	1.82	1.85^c	37.11	39.40	38.25^b
	SS	1.66	1.55	1.61^b	1.92	1.81	1.87^b	35.35	39.74	37.54^b
	CH	1.64	1.58	1.61^b	1.90	1.84	1.87^b	36.20	38.56	37.38^b
	DH	1.62	1.66	1.64^a	1.88	1.92	1.90^a	37.02	38.37	36.19^c
	NT	1.54	1.55	1.54^d	1.80	1.81	1.81^b	40.18	39.67	39.92^a
$\bar{X}$		1.61^A	1.58^B	1.60	1.88^A	1.84^B	1.86	37.17^B	38.55^A	37.86

Tt: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiselling, DH: disk-harrowing, NT: no-till); Stag – Stagnosol (Cacinci); Gley – Gleysol (Magadenovac); ρ_b-bulk density, g cm^{-3}; PD-packing density, g cm^{-3}; P-total porosity; $\bar{X}$; mean-average data values; values within the same row followed by different big letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$; values within the same columns followed by different small letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$.

Table 6
The effect of soil tillage on selected soil compaction physical parameters on experimental sites in 2014.

Year (2014)		ρ_b			PD			P		
Soil depth (cm)	Tt	Stag	Gley	$\bar{X}$	Stag	Gley	$\bar{X}$	Stag	Gley	$\bar{X}$
0-20	CT	1.33	1.49	1.41^b	1.59	1.76	1.67^b	48.36	41.86	45.11^a
	SS	1.38	1.51	1.44^a	1.64	1.77	1.71^b	46.25	41.39	43.82^b
	CH	1.33	1.48	1.41^b	1.59	1.75	1.67^b	48.17	42.22	45.20^a
	DH	1.37	1.63	1.50^a	1.64	1.90	1.77^a	46.57	36.39	41.48^b
	NT	1.27	1.53	1.40^b	1.53	1.79	1.66^b	50.55	40.54	45.55^a
$\bar{X}$		1.34^B	1.53^A	1.43	1.60^B	1.79^A	1.70	47.98^A	40.48^B	44.23
20-40	CT	1.42	1.55	1.49	1.69	1.81	1.75	44.61	39.67	41.14
	SS	1.47	1.61	1.54	1.73	1.88	1.80	42.73	37.22	39.98
	CH	1.39	1.63	1.51	1.66	1.89	1.77	45.76	36.71	41.23
	DH	1.44	1.67	1.55	1.70	1.93	1.82	44.04	34.97	39.50
	NT	1.45	1.69	1.57	1.71	1.96	1.83	43.70	34.07	38.89
$\bar{X}$		1.43^B	1.63^A	1.53	1.70^B	1.89^A	1.79	44.17^A	36.53^B	40.35
40-60	CT	1.55	1.59	1.57^b	1.81	1.85	1.83^b	39.63	38.05	38.84^a
	SS	1.57	1.58	1.58^b	1.83	1.84	1.84^b	38.83	38.52	38.68^a
	CH	1.61	1.59	1.60^a	1.87	1.85	1.86^a	37.41	38.06	37.73^b
	DH	1.54	1.57	1.56^b	1.80	1.84	1.82^b	40.00	38.79	39.39^a
	NT	1.55	1.60	1.57^b	1.81	1.86	1.84^b	39.85	37.69	38.77^a
$\bar{X}$		1.56^B	1.59^A	1.58	1.83^B	1.85^A	1.84	39.14^A	38.22^B	38.68

Tt: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiselling, DH: disk-harrowing, NT: no-till); Stag – Stagnosol (Cacinci); Gley – Gleysol (Magadenovac); ρ_b-bulk density, g cm^{-3}; PD-packing density, g cm^{-3}; P-total porosity; $\bar{X}$; mean-average data values; values within the same row followed by different big letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$; values within the same columns followed by different small letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$.

each experimental year show lower values of ρ_b in 2014, on each soil tillage treatment up to a depth of 40 cm (Table 6). However, in the 40–60 cm soil layer the value of ρ_b on SS increased from 1.51 to 1.66 g cm^{-3} and on DH from 1.55 to 1.63 g cm^{-3} (Appendix A1).

On the Gleysol soil type (the fieldMagadenovac), the lowest ρ_b value was recorded on CH (1.49 g cm^{-3}) in the topsoil layer (0–20 cm) and the highest in this layer on DH (1.54 g cm^{-3}) (Fig. 1). In comparison to the Stagnosol soil type, a higher ρ_b on Gleysol was recorded in the mid soil layer (20–40 cm) on SS, CH, DH and NT (1.61–1.65 g cm^{-3}) and points to the high compaction. On all soil tillage treatment values of the Pearson's coefficients indicate increasing ρ_b with increasing depth. Moderate positive correlation ($r = 0.52$) was recorded only on CH and negligible correlation on DH and NT. The correlation between clay content and ρ_b at this site has not been determined. Average ρ_b values in 2013 were lower in the upper layer only on DH tillage treatment comparing with ρ_b in 2014, while on the Stagnosol soil type (the field Cacinci in 2013 each soil tillage treatment was with higher value of ρ_b. The mid soil layer (20–40 cm) in 2013 on CT and SS tillage treatment was highly compacted (average ρ_b 1.67 and 1.63 g cm^{-3}). On the lower soil layer (40–60 cm) in 2014 the measured ρ_b values were increased in all soil tillage treatments in comparison with the first experimental year.

3.1.2. Packing density (PD)

The soil type and tillage treatments significantly affected PD ($P < 0.01$) at 0–20 cm, 20–40 cm and 40–60 cm, respectively, in 2013 (maize crop). At Stagnosol a lower PD at 0–20 and 20–40 cm and a higher PD at 40–60 cm compared to Gleysol was recorded. The significantly lower PD was recorded on CT compared to SS and DH (2.25%), CH and NT (2.79%) at depths of 0–20 cm. A different situation was at the depth of 20–40 cm, where a significantly lower PD was recorded at DH treatment compared to other tillage treatments. A significantly higher PD was measured at DH compared to CT, CH and NT treatments at a depth of 40–60 cm. The PD was higher at DH treatment by 2.63% compared to CT, by 1.58% compared to CH and by 4.74% compared to NT, respectively. During 2014 (winter wheat crop), the soil type significantly affected PD at all depths ($P < 0.01$) while soil tillage impact was significant ($P < 0.05$) at depths of 0–20 cm and 40–60 cm. The significantly higher PD was observed at Gleysol at all layers. The highest PD at 0–20 cm was recorded on DH which was significantly higher compared to other soil tillage treatments (for 6.21% from NT, 5.65% from CT and CH and 3.95% from SS) and CH treatment had the significant highest value of PD at a depth of 40–60 cm.

On the Stagnosol soil type (Cacinci) increasing PD values with depth were observed on all tillage treatments. PD recorded in upper soil layer (0–20 cm) ranged from 1.70 (CT) to 1.72 g cm^{-3} (SS), in the mid layer (20–40 cm) from 1.73 (NT) to 1.77 g cm^{-3} (CT) and in the lower layer (40–60 cm) from 1.81 (NT) to 1.84 g cm^{-3} (CH) (Fig. 1C). PD on SS tillage treatment was in low positive correlation with soil depth ($r = 0.46$) and on other tillage treatment in moderate positive correlation ($r = 0.51$ to 0.63). On Stagnosol correlation of PD and clay content was negative. Pearson's coefficient -0.45 on SS tillage treatment indicates low negative correlation and moderate negative correlations ($r = -0.52$ to -0.55) were found for other tillage treatments.

On the Gleysol soil type (soil texture was silty loam with a clay content of 18.30% up to 30 cm and 23.00% below 30 cm) the lowest average PD values (1.66–1.69 g cm^{-3}) were measured in the upper layer (0–20 cm) and belong to the upper optimum range (Fig. 1D). Values of PD on CT, SS and CH increase inversely with soil depth, with higher values measured at a lower soil depth (40–60 cm). The highest average PD value was recorded in the mid soil layer (20–40 cm depth) on DH and NT tillage treatment (1.81 g cm^{-3}). On PD a positive correlation with soil depth was recorded; on DH ($r = 0.48$) and NT ($r = 0.39$) a low positive correlation while other tillage treatments had moderate positive correlation (from $r = 0.52$ to 0.69).

3.1.3. Soil porosity (P)

The soil porosity (P) was significantly affected by soil type ($P < 0.01$) and soil tillage treatment ($P < 0.01$) in 2013 (maize crop). At depths of 0–20 cm and 20–40 cm P was higher at Stagnosol, while at 40–60 cm it was higher at Gleysol. Significantly higher P was recorded on CT compared to SS, DH, CH and NT at depths of 0–20 cm while at a depth of 20–40 cm the highest porosity was recorded at DH treatment. Porosity decreases with depth at 40–60 cm. The highest P was recorded on NT and the lowest on DH treatment. The differences in P between tillage treatments were significant except between SS and DH. During 2014 (winter wheat crop), soil type significantly affected P at all depths ($P < 0.01$) while soil tillage impact was significant ($P < 0.05$) at

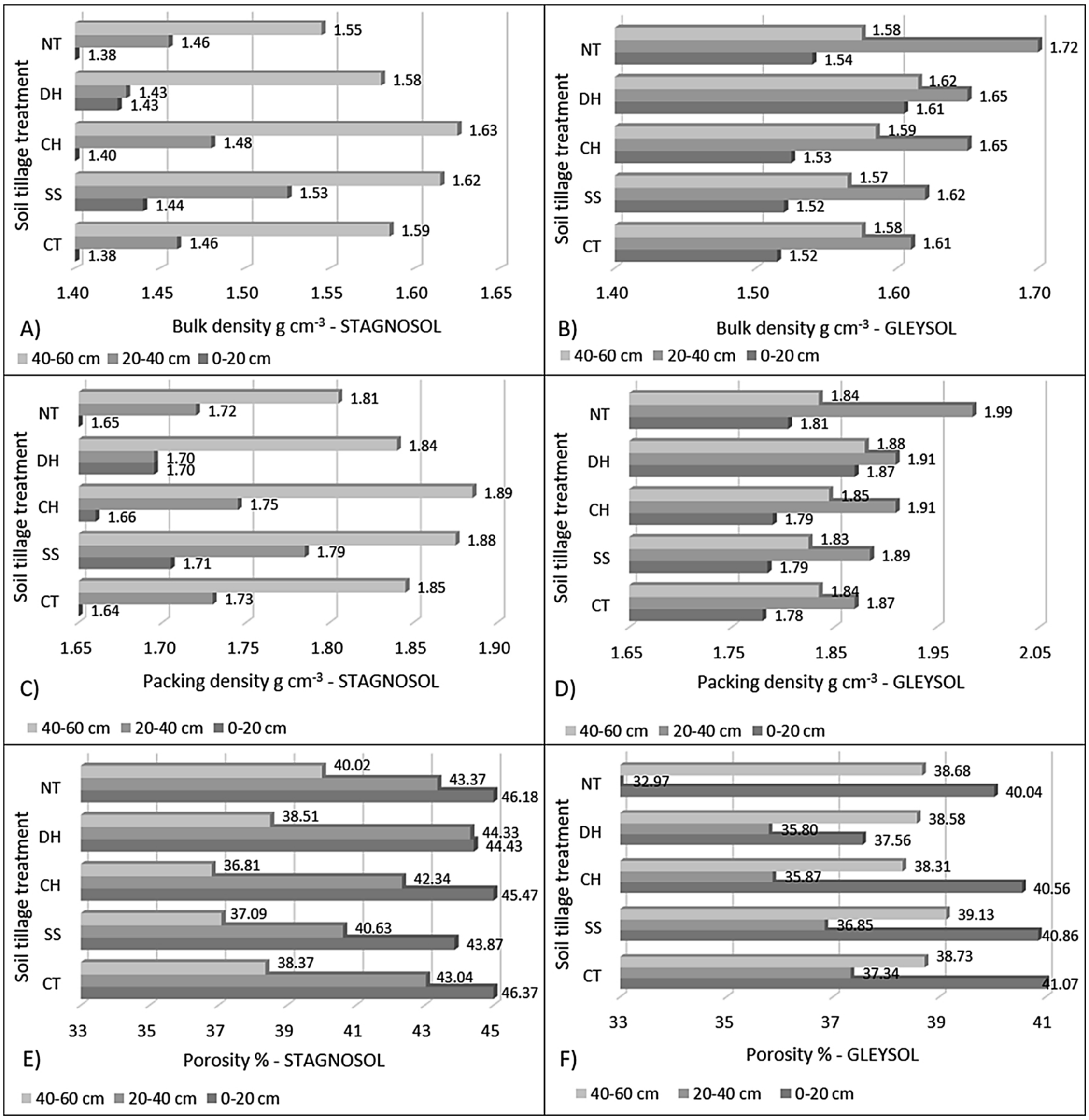

Fig. 1. Average soil physical properties on experimental sites for both experimental years.

depths of 0–20 cm and 40–60 cm. Significantly higher porosity (for 15.63% on 0–20 cm, 17.30% on 20–40 cm and 2.35% on 40–60 cm, respectively) was observed at Stagnosol. At a depth of 0–20 cm the highest values of P were recorded on NT, CH and CT which was significantly higher than DH treatment. On CH a significantly lower was recorded P compared to DH (4.21%), CT (2.85%), NT (2.68%) and SS (2.45%) at a depth of 40–60 cm.

On both experimental fields P values increase inversely with ρ_b and PD, indicating a higher amount of air and lower intensity of compaction. A very high negative correlation between P and ρ_b was found on both fields; on Stagnosol from $r = -0.98$ (CT) to $r = -0.99$ (CH) and on Gleysol from $r = -0.98$ (DH) to $r = -0.98$ (NT). On the Stagnosol soil type the highest values of P on all tillage treatments (Fig. 1E) were measured in the top layer (0–20 cm) with a range from 43.27% to 44.05%. The lowest values of P (36.60–37.60%), on all tillage treatments, were found on 40–60 cm depth (where highest values of ρ_b and PD were recorded). On CT a high negative correlation ($r = -0.75$) was recorded and on other soil tillage treatment moderate negative correlation (from $r = -0.59$ to $r = -0.65$). On the Gleysol soil type the highest value for P (Fig. 1F) was recorded in the soil layer 0–20 cm (38.29–39.27%) while at 20–40 cm soil depth the lowest P value was recorded (37.25–39.87%) as well as for ρ_b. A correlation between soil depth and P was not found on CT, DH and NT tillage treatment. Only on CH tillage treatment significant ($P < 0.01$) Pearson's coefficients with low negative correlation were found.

3.2. Crop productivity

The effects of soil tillage and nitrogen fertilization on crop productivity and soil coverage of crop residues are presented in Table 7A (maize) and 7B (winter wheat).

3.2.1. Maize

On the Stagnosol soil type (the field Cacinci), the grain yield was not significantly affected by soil treatment or nitrogen fertilization. Biological yield and harvest index were significantly affected by soil tillage treatment ($P < 0.05$). On the Gleysol soil type (Magadenovac field), grain yield and biological yield were under significant influence of tillage treatments ($P < 0.01$) and nitrogen fertilization ($P < 0.01$ for grain yield and $P < 0.05$ for biological yield). The harvest index was not significantly affected by soil treatment or nitrogen fertilization. The grain yield and biological yield on NT was significantly lower

Table 7A
The effects of soil tillage and nitrogen fertilization treatments on maize productivity (grain yield, biological yield and harvest index) and soil crop residue cover on experimental sites.

Tt	Grain yield (t ha^{-1})			$\bar{X}_T$	Biological yield (t ha^{-1})			$\bar{X}_T$	Harvest index (%)			$\bar{X}_T$	Soil cover crop residue (%)			$\bar{X}_T$
	N1	N2	N3		N1	N2	N3		N1	N2	N3		N1	N2	N3	
	Maize (Stagnosol-Cacinci)															
CT	10.10	11.00	9.60	10.24	42.61	46.80	39.46	42.96^{A}	23.00	23.33	23.00	23.11^{B}	3.00	3.00	4.33	3.44^{E}
SS	6.86	8.80	11.02	8.89	26.26	35.02	40.34	33.87^{B}	25.33	24.67	27.33	25.78^{A}	34.00	34.67	39.33	36.00^{C}
CH	6.83	10.90	8.75	8.83	27.25	40.88	33.20	33.78^{B}	24.67	26.33	25.67	25.56^{A}	50.33	52.67	54.00	52.33^{B}
DH	8.14	9.74	8.49	8.79	31.74	35.23	29.24	32.07^{B}	25.00	27.33	29.00	27.11^{A}	27.33	28.33	30.67	28.78^{D}
NT	9.05	9.03	8.94	9.00	35.13	33.69	32.89	33.90^{B}	25.33	26.00	26.67	26.00^{A}	95.67	99.67	100.00	98.44^{A}
$\bar{X}_N$	8.20	9.90	9.36	9.15	32.63	38.33	35.03	35.33	24.67	25.53	26.33	25.51	42.07^{c}	43.67^{b}	45.67^{a}	43.80
	$F_T = 1.78^{ns}$				$F_T = 6.99$*(LSD 5.35)				$F_T = 4.07$*(LSD 2.37)				$F_T = 5504.98$**(LSD 1.55)			
	$F_N = 2.41^{ns}$				$F_N = 2.11^{ns}$				$F_N = 2.58^{ns}$				$F_N = 34.05$**(LSD 0.91)			
	Maize (Gleysol-Magadenovac)															
CT	12.03	17.08	14.74	14.62^{A}	44.52	62.02	53.55	53.36^{A}	26.93	27.47	27.53	27.31	3.67	4.33	5.33	4.44^{E}
SS	13.88	17.28	14.56	15.24^{A}	53.74	60.34	55.04	56.37^{A}	26.10	28.57	26.43	27.03	44.33	45.33	48.67	46.11^{C}
CH	11.49	14.23	16.41	14.04^{A}	43.56	56.57	66.04	55.39^{A}	26.80	25.20	24.83	25.61	54.33	55.33	58.00	55.89^{B}
DH	11.75	15.07	15.71	14.18^{A}	45.39	58.09	58.70	54.06^{A}	25.73	25.97	26.83	26.18	28.33	29.00	31.00	29.44^{D}
NT	9.72	9.20	8.83	9.25^{B}	38.79	35.49	32.43	35.57^{B}	25.10	26.27	27.10	26.16	95.33	99.33	100.00	98.22^{A}
$\bar{X}_N$	11.77^{b}	14.57^{a}	14.05^{a}	13.47	45.20^{b}	54.50^{a}	53.15^{a}	50.95	26.13	26.69	26.55	26.46	45.20^{c}	46.67^{b}	48.60^{a}	46.82
	$F_T = 10.00$**(LSD 2.48)				$F_T = 11.30$**(LSD 8.42)				$F_T = 1.95^{ns}$				$F_T = 2932.70$**(LSD 2.09)			
	$F_N = 6.84$**(LSD 1.68)				$F_N = 5.17$*(LSD 6.52)				$F_N = 0.41^{ns}$				$F_N = 27.65$**(LSD 0.96)			

Tt: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiselling, DH: disk-harrowing, NT: no-till), N1: reduced nitrogen fertilization, N2: optimal nitrogen fertilization, N3: luxury nitrogen fertilization, F_T: F test for tillage treatments, F_N: F test for nitrogen treatments, ns: not significant, * significant at $P < 0.05$, ** significant at $P < 0.01$. Values within the same column followed by different big letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$. Values within the same row followed by different small letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$.

compared to CT, SS, DH and CH between which no significant differences were detected. Maize on reduced nitrogen fertilization, on the Gleysol soil type, had a significantly lower grain and biological yield compared to other fertilization treatments between which there was no significant difference. Soil cover crop residues were significantly affected by soil treatment. Residue cover after sowing was greater under NT than under CH, SS, DH and CT. All differences between residue cover in all tillage treatments were statistically significant. Nitrogen fertilization had a significant effect on soil coverage of crop residues. The highest soil coverage was measured on the luxurious fertilization, while the smallest coverage of harvested remains was observed on reduced nitrogen fertilization.

3.2.2. *Winter wheat*

On the Stagnosol soil type (Cacinci), the grain yield and biological yield were significantly affected by soil tillage ($P < 0.01$) and nitrogen fertilization ($P < 0.05$ for grain yield and $P < 0.01$ for biological yield). The grain yield on SS and CH tillage treatments was significantly

Table 7B
The effects of soil tillage and nitrogen fertilization treatments on winter wheat productivity (grain yield, biological yield and harvest index) and soil crop residue cover on experimental sites.

Tt	Grain yield (t ha^{-1})			$\bar{X}_T$	Biological yield (t ha^{-1})			$\bar{X}_T$	Harvest index (%)			$\bar{X}_T$	Soil cover crop residue (%)			$\bar{X}_T$
	N1	N2	N3		N1	N2	N3		N1	N2	N3		N1	N2	N3	
	Winter wheat (Stagnosol-Cacinci)															
CT	4.17	5.38	3.96	4.50^{B}	9.49	13.22	13.14	11.95^{B}	43.65	40.69	31.78	38.71^{B}	3.33	3.67	4.67	3.89^{E}
SS	5.39	5.95	6.41	5.92^{A}	13.08	14.80	14.79	14.22^{A}	41.35	40.25	43.74	41.78^{AB}	34.67	35.00	40.13	36.67^{C}
CH	6.14	6.07	5.63	5.95^{A}	10.06	9.88	12.55	11.16^{BC}	62.15	63.01	41.60	55.58^{A}	51.00	52.33	54.67	52.67^{B}
DH	4.08	4.99	5.47	4.85^{B}	9.51	10.65	10.64	10.27^{C}	43.07	46.73	51.71	47.17^{AB}	28.00	30.00	32.67	30.22^{D}
NT	4.16	4.79	5.49	4.81^{B}	9.48	11.15	11.31	10.65^{BC}	43.83	42.98	48.62	45.14^{AB}	96.67	99.67	100.00	98.78^{A}
$\bar{X}_N$	4.79^{b}	5.44^{a}	5.39^{a}	5.21	10.33^{b}	11.94^{a}	12.69^{a}	11.65	46.81	46.73	43.49	45.68	42.73^{c}	44.13^{b}	46.47^{a}	44.44
	$F_T = 7.41$** (LSD 0.81)				$F_T = 11.43$**(LSD 1.51)				$F_T = 6.18$**(LSD 11.19)				$F_T = 20,354.44$**(LSD 0.80)			
	$F_N = 5.74$*(LSD 0.45)				$F_N = 11.67$**(LSD 1.04)				$F_N = 1.30^{ns}$				$F_N = 43.26$**(LSD 0.85)			
	Winter wheat (Gleysol-Magadenovac)															
CT	4.86	6.40	6.82	6.03^{AB}	11.55	13.91	14.26	13.24^{BC}	41.63	45.8	47.59	45.02	4.00	4.67	5.67	4.78^{E}
SS	5.84	7.39	9.19	7.47^{A}	13.33	15.28	20.12	16.24^{A}	43.71	48.34	45.73	45.93	44.33	46.00	49.00	46.44^{C}
CH	3.53	6.24	6.45	5.41^{B}	8.25	12.37	14.29	11.64^{C}	43.00	50.47	45.14	46.20	55.33	56.33	59.00	56.89^{B}
DH	4.34	9.11	8.53	7.33^{A}	9.55	19.09	14.70	14.45^{AB}	45.47	47.60	57.47	50.08	30.00	30.67	32.67	31.11^{D}
NT	3.91	6.74	8.63	6.43^{AB}	8.17	14.22	17.82	13.40^{BC}	47.62	47.44	48.26	47.77	98.00	99.33	100.00	99.11^{A}
$\bar{X}_N$	4.50^{c}	7.18^{b}	7.92^{a}	6.53	10.17^{c}	14.98^{b}	16.24^{a}	13.79	44.29^{b}	47.94^{a}	48.84^{a}	47.02	46.33^{c}	47.40^{b}	49.27^{a}	47.67
	$F_T = 6.54$*(LSD 1.63)				$F_T = 5.50$*(LSD 2.36)				$F_T = 1.94^{ns}$				$F_T = 7945.31$**(LSD 1.27)			
	$F_N = 85.59$** (LSD 0.58)				$F_N = 138.90$**(LSD 0.80)				$F_N = 6.03^{**}$(LSD 2.90)				$F_N = 54.12$**(LSD 0.60)			

Tt: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiselling, DH: disk-harrowing, NT: no-till), N1: reduced nitrogen fertilization, N2: optimal nitrogen fertilization, N3: luxury nitrogen fertilization, F_T: F test for tillage treatments, F_N: F test for nitrogen treatments, ns: not significant, * significant at $P < 0.05$, ** significant at $P < 0.01$. Values within the same column followed by different big letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$. Values within the same row followed by different small letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$.

higher in relation to CT, DH and NT. The differences in wheat grain yield on SS and CH were not statistically significant as well as differences in grain yields on CT, DH and NT. Reduced nitrogen fertilization resulted in a significantly lower grain yield and biological yield compared to optimal and luxury nitrogen fertilization while between these treatments there was no significant difference in grain yield. The biological yield on SS treatment was significantly higher in relation to CT, CH, DH and NT. The harvest index was significantly affected by soil treatment ($P < 0.01$). Only significant difference was detected between CH and CT tillage treatments. All differences between residue cover in all tillage and fertilization treatments were statistically significant and decreasing in following order: NT > CH > SS > DH > CT for soil tillage treatments and N3 > N2 > N1 for nitrogen fertilization treatment.

On the Gleysol soil type (Magadenovac), soil tillage ($P < 0.05$) and nitrogen fertilization ($P < 0.01$) had significantly influenced grain yield and biological yield. The grain yield on SS and DH tillage treatments were significantly higher in relation to CH while other differences were not statistically significant. The biological yield on SS treatment was significantly higher in relation to CT, CH, and NT. With increasing the rate of nitrogen grain yield and biological yield increased. Reduced nitrogen fertilization resulted in a significantly lower harvest index compared to optimal and luxury nitrogen fertilization while between these treatments there was no significant difference. Soil cover crop residues were significantly affected by soil treatment and nitrogen fertilization ($P < 0.01$). All the differences between residue cover in all tillage and fertilization treatments were statistically significant. Residue cover after sowing increased in the following order: CT < DH < SS < CH < NT for soil tillage treatments and N1 < N2 < N3 for nitrogen fertilization treatment.

3.3. Nitrogen use efficiency (NUE)

Nitrogen use efficiency (NUE) in response to tillage systems and nitrogen application rate was related to crop type and soil type. In case of maize grown on the Stagnosol soil type (Cacinci) the NUE decreased with increasing N application rate under all tillage systems (Table 8). In general, the NUE values were higher for CT than for conservation tillage treatments, including SS, CH, DH and NT irrespective of nitrogen fertilization rate. Similarly, grain yields and biological yields were greater under CT than conservation tillage systems. Averaged values of NUEs for all nitrogen application rates with grain yield were 54.7 kg kg^{-1} for CT and from 45.1 to 48.0 kg kg^{-1} under all conservation tillage systems. Averaged values for all tillage systems were 58.5, 49.95 and 36.0 kg kg^{-1} for N1, N2 and N3, respectively.

For maize grown on the Gleysol soil type (Magadenovac), similarly as with the Stagnosol soil type (Cacini) the NUEs decreased with increasing nitrogen application rate irrespective of the tillage system (Table 8). It is worth noting that the highest NUE values for N1 and N2 under SS coincided with the highest grain yield and the lowest NUE under NT – with the lowest yield. Irrespective of nitrogen application rate the NUE was substantially lower for NT (47.1 kg kg^{-1}) than for other tillage treatments (68.4-76.2 kg kg^{-1}). Similarly, as with the Stagnosol soil type (Cacini) the NUE, as averaged for all tillage systems, decreased with increasing nitrogen application rate from 78.5 under N1 to 52.0 kg kg^{-1} under N3. In the majority of comparable treatments both the NUEs and crop yield were higher in the Gleysol soil type (Magadenovac) than the Stagnosol soil type (Cacini).

The NUEs for winter wheat grown on Stagnosol-Cacini decreased with increasing nitrogen application rate under all tillage treatments (Table 8). It is worth noting that the highest NUEs under SS and CH (53.2–54.9 kg kg^{-1}) at all nitrogen application rate correspond with highest grain yields (5.92–5.95 t ha^{-1}). The NUE values, as averaged for all tillage systems decreased with increasing nitrogen application rate whereas grain yield and biological yield were significantly greater under N2 and N3 than under N1. Statistically significant differences in NUE values were found between all nitrogen application rates (Table 8). Increasing nitrogen application rate was accompanied by increasing grain yield, biological yield and decreasing NUEs.

As can be seen from Table 8 the NUEs for biological yield of winter wheat grown on the Gleysol soil type (Magadenovac) was under significant influence of tillage systems and nitrogen fertilization while grain yield was under significant influence of tillage systems. NUEs decreased with increasing nitrogen application for CT and SS treatment, while on DH, CH and NT treatments response was different. Irrespective of the N application rate the NUEs and grain yields were highest for SS and lowest for CH. Interestingly, the maxima of NUE (65.1 kg kg^{-1}) and grain yield (9.11 t ha^{-1}) occurred at a combination of DH and N2. Also averaged values of NUEs for all tillage systems reached a maximum under N2 indicating that increase of nitrogen application rate from N1 to N2 results in greater fertilizer N recovery efficiency in contrast to both maize and winter wheat grown on the Stagnosol soil type (Cacinci) site and maize grown on this site where the NUEs in general decreased successively with increasing nitrogen application rate from N1 to N3.

The direction of changes in NUEs for biological yield in response to tillage systems and nitrogen rates was the same as for grain yield irrespective of crop type and experimental site.

4. Discussion

4.1. Weather conditions

In both experimental year weather conditions (mainly precipitation and air temperature) were not common in comparison to the 30-yr average. During the whole vegetation period and especially during the most intensive and critical growing period (April-June for winter wheat and April-August for maize) in both years and both sites, precipitation and air temperature most often were higher than the multi-year average (Table 1). The exchange of extremely humid and extremely dry periods continued throughout the entire maize vegetation (2013 year), as well as during most of the winter wheat vegetation (2013/2014 year).

4.2. Soil physical properties

The statistical results of the study indicated that soil type ($P < 0.01$) and soil tillage treatment ($P < 0.01$ for 2013; $P < 0.05$ for 2014) affected ρ_b, PD and P. Higher values of ρ_b and PD were recorded at Gleysol compared to Stagnosol. For porosity (P), the situation was reversed. In additional comparison of Gleysol and Stagnosol, the greatest increase in ρ_b of 14.28% and PD of 11.38% was observed under CH treatment in the layer of 0–60 cm in 2014. Similar results regarding ρ_b increase on NT treatment were also reported by Asenso et al. (2018). The lowest ρ_b was recorded at CT treatment up to ploughing depth followed by a 11.34% increase at 40–60 cm. Minimal average increase of ρ_b from 5.79% was observed under SS treatment in 0–60 cm soil depth and this might be due to the deepest soil tillage (up to 40 cm) which induced better water infiltration and aeration. The consistent improvement in overall soil porosity under CST treatments in both experimental years was most probably related to increased aggregate stability, enhanced by minimum tillage, residue cover, and biological activity. These treatments had a better distribution of soil pores which is important for crop growth because it influences on soil aeration and water availability through increased connectivity and drainage for enhanced root development.

Statistical analysis of the data indicates that ρ_b and PD increased with the soil depth on the Stagnosol soil type in both experimental years (Appendix A1) and the Pearson's coefficient for both parameters indicates a moderate positive correlation (Table 4). Ismail et al. (1994) reported significant increase ρ_b value with the depth but without any further differences between CT and NT treatments. Increase of soil ρ_b in the cultivated layer has a negative effect on the growth and development of agricultural crops. Soils with high ρ_b in deeper layers (e.g.

40–60 cm) develop poor internal drainage and that can negatively affect root growth, resulting in a substantial yield decrease.

The low negative correlation of ρ_b and clay content on SS treatment (r = -0,476**) and moderate negative correlation on other tillage treatments are in line with the results reported in Chaudhari et al. (2013). In 2014, ρ_b and PD in all tillage treatments was lower up to 40 cm, and in the upper layer (0–20 cm). These results, according Kaufmann et al. (2010) and related to PD parameter, indicate an optimum range for plant grow. Dam et al. (2005) reported (based on an 11-year experiment) that the values of ρ_b vary the most in the surface layer up to 10 cm, but without significant differences between CT, NT and RT (reduced tillage). Only in 2014, in the medium soil layer depth (20–40 cm) values of ρ_b and PD were lower on all tillage treatments and reduction varied from 5.4% on CT to < 1% on DH. Wang et al. (2015) reported no significant difference between SS and NT tillage treatment in the 30–50 cm soil profile layer. Measured PD values (above 1.70 g cm^{-3} on all tillage treatments) indicate a limiting range for plant growth (Kaufmann et al., 2010). Higher ρ_b and PD values measured on DH tillage treatment (especialy on the 40–60 cm soil depth) are in accord with those reported by Hazelton and Murphy (2007). P values were in a very strong negative correlation with ρ_b and PD on both experimental fields - soil types, and same conclusion was stated by Balan et al. (2009).

Analysis of the data for the Gleysol soil type revealed very strong positive correlation of clay content and soil depth (Table 4) in both experimental years. The highest values of ρ_b and PD were measured in the soil layer at 20–40 cm. The values of ρ_b were greater at all tillage treatments in both experimental years during growing season which is similar to the results Asenso et al. (2018). In 2014, the values of ρ_b and PD in the upper layer 0–20 cm increased the most on NT treatment. Wang et al. (2015) reported similar results and Kushwaha et al. (2001) stated about 10% higher ρ_b values on NT in comparison to CT treatment. The mid soil layer 20–40 cm, in comparison to the upper layer, has lower values of ρ_b and PD on CT (6.5%) and SS (1.9%) while on others treatment the values were higher by around 2%, and those results are in line with the results of Wang et al. (2015). At the deepest soil layer (40–60 cm, clay content 23%) lower values of ρ_b and PD were measured on CT (< 1%) while on other treatments values were withot changes, except on NT in 2013. According to Li et al. (2007), investigation of the influence of NT and CT on ρ_b in a 15-year field experiment, in the first few years, the surface ρ_b was significantly lower under CT compare to NT. After few years, ρ_b of both treatments were similar, and in the last two years, ρ_b became slightly lower under no-tillage.

4.3. Crop productivity

4.3.1. Maize

During the most sensitive phase of maize growing according to need for water, in periods of tasseling and silking, dry and humid periods were exchanged very often but without the lack of water in the plant - maize. Due to this fact the pollination of maize was found to be of a satisfactory level, which ultimately reflected on the maize grain yield. Statistical results analyses of the study indicated that tillage treatments significantly ($P < 0.05$) affected biological yield of maize and harvest index at the Stagnosol soil type (Cacinci). At the other experimental site (Magadenovac), on the Gleysol soil type, soil tillage and nitrogen fertilization treatments have significantly influenced grain yield ($P < 0.01$) and biological yield of maize ($P < 0.01$ for tillage and $P < 0.05$ for nitrogen fertilization). On Stagnosol, no significant effect on maize grain yield was observed due to tillage treatment or N management regimes which is consistent with the results Huang et al. (2015). Conservation tillage (with surface mulch - crop residues) may contribute to an increasing infiltration rate of soils, which may result in an increase in nitrate leaching loss and in such conditions the nitrogen fertilization effect may be absent. Conventional tillage recorded higher biological yield compared with conservation tillage treatments and these results are in agreement with the results of Gul et al. (2009). According to Borin and Sartori (1995), the highest maize yield had been obtained with conventional tillage compared with minimum tillage and no tillage. Significantly higher harvest index (27.11% -DH, 26.00% - NT, 25.78% - SS, 25.56% −CH) on Stagnosol was recorded on conservation tillage treatments compare to CT (23.11%). Similar results were obtained from Asenso et al. (2018) who reported that SS treatment improved the harvest index of maize for 1.97% than NT treatment. At Magadenovac, on Gleysol, significantly lower grain yield and biological yield (which corresponds to Khorami et al., 2018) of maize was recorded on no-till treatment compared to CT, SS, DH and CH between which no significant differences were detected. The highest yields were achieved on SS treatment probably because better root development that allows better nitrogen assimilation and remobilization in maize which results in increased yield. Wang et al (2015) suggest that the SS treatment improved the spatial distribution of root density, soil moisture and N states, thereby promoting the absorption of soil moisture and reducing N leaching via the root system in the 20–50 cm layer of the profile. Mafongoya et al. (2016) as well as our experiences (Jug et al. (2007) showed that grain yields on NT treatment were significantly lower than at the CT treatment, while Lal (1997) concluded on several years' experiments that maize achieves significantly higher yields on no-till treatment than on the ploughing. Differences in the results obtained are probably associated with the regime of precipitation in the vegetation period. Conservation tillage treatment has a significant effect on the yield in dry years, while in the years with increased rainfall some benefits from these treatments do not come fully to the point of expression. According to Huang et al. (2015) the effect of NT on crop yields varies depending on climate and soil type. The lowest biological yield was recorded on no-till treatment which is confirmed by numerous surveys of maize cultivation with no-till system (Acharya and Sharma, 1994; Arora et al., 1991; Sileshi et al., 2006; Ahmad et al., 2010). SS treatment improved the biological yield up to 5.64% than the NT treatment which is consistent with the results Asenso et al. (2018).

4.3.2. Wheat

The results of statistical analyses indicated that soil tillage and nitrogen fertilization treatments significantly affected grain and biological yield of winter wheat on both experimental ields. On the Stagnosol soil type (Cacinci), the highest grain yield of winter wheat was recorded on CH and SS treatments and there were significantly higher in comparison to grain yield on CT, DH and NT treatments. We hypothesized that subsoiling treatment improved water infiltration and consequently soil water storage which increased grain yield of wheat. We suppose that wheat grain yield increased due to improved root environment and additional soil water. According to Hemmat and Eskandari (2006) average grain yields of winter wheat on RH tillage treatment (chisel ploughing + disk) and NT (no till) were significantly greater (25–42%) than grain yields using CT (conventional tillage) treatment which is partially in line with the results of this research. Wheat grain and biological yield on reduced fertilization was significantly lower in relation to optimal and luxurious fertilization between which there were no significant differences. Zhang et al. (2011) suggested that balanced fertilization combined with subsoiling had the best effect in soil water conservation and grain yield increase which is consistent with the results obtained. Habbib et al. (2017) found that five years after transition from a conventional to no-till system, the yield of wheat remains stable. De Vita et al. (2007) point out that the advantages of direct sowing can only be seen in dry climatic areas or during dry season with poor precipitation. Feng et al. (2014) in their research recommend the use of reduce tillage and reduced nitrogen fertilization (by 25%) in wheat and maize production in sustainable production. On the Gleysol soil type (Magadenovac), the highest grain and biological yields were achieved on luxurious nitrogen fertilization (9.34% higher in comparison to optimal nitrogen fertilization and 43.18% higher in compare to reduced

Table 8
The effects of soil tillage and nitrogen application rates on NUE (kg kg^{-1}) on experimental sites.

Tt	NUE_{GY}			$\bar{X}_T$	NUE_{BY}			$\bar{X}_T$
	N1	N2	N3		N1	N2	N3	
Maize (Stagnosol-Cacinci)								
CT	72.2	55.0	36.9	54.7	304.3	234.0	151.8	230.0^A
SS	49.0	44.0	42.4	45.1	187.5	175.1	155.2	172.6^B
CH	48.8	54.5	33.7	45.6	194.6	204.4	127.7	175.6^B
DH	58.2	48.7	32.7	46.5	226.7	176.2	112.5	171.8^B
NT	64.6	45.1	34.4	48.0	252.2	168.5	126.5	182.4^B
$\bar{X}_N$	58.5^a	49.5^b	36.0^c	48.0	233.1^a	191.6^b	134.7^c	186.5
	$F_T = 1.14^{ns}$				$F_T = 3.85^*$			
	$F_N = 16.05^{**}$				$F_N = 25.64^{**}$			
Maize (Gleysol-Magadenovac)								
CT	80.2	81.4	54.6	72.0^A	296.8	295.3	198.3	263.5^A
SS	92.5	82.3	53.9	76.2^A	358.3	287.3	203.9	283.2^A
CH	76.6	67.8	60.8	68.4^A	290.4	269.4	244.6	268.1^A
DH	78.3	71.8	58.2	69.4^A	302.6	276.6	217.4	265.5^A
NT	64.8	43.8	32.7	47.1^B	258.6	169.0	120.1	182.6^B
$\bar{X}_N$	78.5^a	69.4^a	52.0^b	66.6	301.3^a	259.5^b	196.9^c	252.6
	$F_T = 7.68^{**}$				$F_T = 6.42^*$			
	$F_N = 17.97^{**}$				$F_N = 18.58^*$			
Winter wheat (Stagnosol-Cacinci)								
CT	52.1	44.8	26.4	41.1^B	118.7	110.1	87.6	105.5^B
SS	67.4	49.5	42.7	53.2^A	163.5	123.3	98.6	128.4^A
CH	76.7	50.6	37.5	54.9^A	125.7	82.3	90.3	99.4^{BC}
DH	51.0	41.6	36.5	43.0^B	119.0	88.7	70.9	92.9^C
NT	52.0	39.9	36.6	42.8^B	118.5	92.9	75.4	95.6^{BC}
$\bar{X}_N$	59.9^a	45.3^b	35.9^c	47.0	129.1^a	99.5^b	84.6^c	104.4
	$F_T = 8.20^{**}$				$F_T = 12.3^{**}$			
	$F_N = 46.89^{**}$				$F_N = 51.40^{**}$			
Winter wheat (Gleysol-Magadenovac)								
CT	50.1	45.7	37.9	44.6^{BC}	119.1	99.4	79.2	99.2^B
SS	60.2	52.8	51.1	54.7^A	137.5	109.1	111.8	119.5^A
CH	36.4	44.6	35.8	38.9^C	85.1	88.3	79.4	84.3^C
DH	44.8	65.1	47.4	52.4^{AB}	98.5	136.4	81.7	105.5^B
NT	40.3	48.1	48.0	45.5^{BC}	84.2	101.6	99.0	94.9^{BC}
$\bar{X}_N$	46.3	51.3	44.0	47.2	104.9^a	107.0^a	90.2^b	100.7
	$F_T = 5.19^{**}$				$F_T = 8.80^{**}$			
	$F_N = 2.94^{ns}$				$F_N = 7.19^{**}$			

Tt: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiselling, DH: disk-harrowing, NT: no-till), N1: reduced nitrogen fertilization, N2: optimal nitrogen fertilization, N3: luxury nitrogen fertilization, NUE_{GY}: nitrogen use efficiency for grain yield (kg kg^{-1}), NUE_{BY}: nitrogen use efficiency for biological yield (kg kg^{-1}), F_T: F test for tillage treatments, F_N: F test for nitrogen treatments, ns: not significant, * significant at $P < 0.05$, ** significant at $P < 0.01$. Values within the same column followed by different big letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$. Values within the same row followed by different small letter(s) are statistically different using protected least significant difference (LSD) test at $P < 0.05$.

nitrogen fertilization). The difference between optimal and reduced nitrogen fertilization was significant which indicates the importance of sufficient nitrogen supply for high and stabile yields. Absence of the negative impact of luxury fertilization is probably the culmination of an increase in rainfall in the vegetation period of winter wheat leading to nitrogen leaching. In such conditions, optimal nitrogen fertilization could not provide satisfactory yields. Avoiding over fertilization is the first and primary means to match a high use efficiency and economic return of N-fertilizer with limited environmental risks from nitrate leaching. According to Agostini et al. (2010) many environmental factors (temperature, rainfall, soil texture, etc.) can affect the nitrogen use efficiency as they affect either crop growth and development or the N availability from the soil through effects on mineralization of SOM and organic fertilizers and on nitrate leaching. Soil tillage treatments have significant influence on harvest index only on Stagnosol soil type (Cacinci) while at Gleysol soil type (Magadenovac), harvest index was influenced only by nitrogen fertilization. A significantly lower harvest index was recorded on reduced nitrogen fertilization treatment (44.29%) compared to optimal (47.94%) and luxury (48.84%). The difference between optimal and luxury nitrogen fertilization was not significant which is in accordance with the results of Mosanaei et al. (2017). Li et al. (2012) indicated that the optimized N management increased the harvest index, yield and N use efficiency by decreasing the N application rate and postponing N application time, improved wheat population quality, controlled excessive growth in the vegetative stages and increased dry matter and N accumulation rates after heading.

4.4. Crop residue

Crop residue management is an integral component of conservation tillage systems. Soil cover crop residues were significantly affected by soil tillage treatment and nitrogen fertilization ($P < 0.01$) for maize and wheat at both experimental sites. All differences between residue cover in all tillage and all nitrogen fertilization treatments were statistically significant. Residue cover after sowing was decreasing in following order: NT > CH > SS > DH > CT. These results are in accordance with results Veiga et al. (2010) who reported that soil residue cover after tillage and sowing operations was 88% in no-tillage (NT), 38% in chisel ploughing (CP) and less than 10% in conventional tillage. Increasing the amount of nitrogen increased soil coverage. All the differences between nitrogen fertilization were significant. Nitrogen increases the production of biomass by increasing cell growth and contributing to the absorption of other micro and macro nutrients.

4.5. Nitrogen use efficiency (NUE)

The NUE values for maize in response to nitrogen application rate and tillage systems were related to site conditions. In the Stagnosol soil type (Cacinci), lower and similar NUEs under No-till and other conservation tillage systems than under conventional system can be due to N immobilisation in crop residues (Newton, 2001; Grahmann et al., 2013) and resulting in low nitrogen availability for plant roots. The N immobilisation can be a result of commonly wide C:N ratio of cereal crop residues by providing high carbon input. However, the highest NUEs under subsoiling (SS) for both the lowest (N1) and medium (N2) nitrogen application rates could be explained by loosening strong subsoil and enhanced root growth and improved N uptake compared to N3 from greater soil depth. It is worth noting that the NUEs for winter wheat in the Gleysol soil type (Magadenovac) were the highest for N2 under most tillage systems in contrast to maize in both experimental fields and winter wheat in the Stagnosol soil type (Cacini) where the NUEs were highest for N1. The greater NUEs for N2 at the Gleysol soil type (Magadenovac) compared to the Stagnosol soil type (Cacini) can be associated with a greater overall quality and productivity as indicated by a greater mean grain yield (irrespective of tillage systems and N application rates) for both maize (13.47 vs. 9.15 t ha^{-1}) and winter wheat (6.53 vs. 5.21 t ha^{-1}) in the Gleysol soil type (Magadenovac).

Analysis of NUEs values and crop yield (Tables 8, 7A and 7B) responses to the applied nitrogen rates indicate variation in yields (from increasing to decreasing) depending on the tillage treatment or experimental field. At the same time NUE values somewhat decreased or increased from N1 to N2 and considerably decreased from N2 to N3. This implies that from point of view NUE the lowest nitrogen application rate is reasonable, however while considering both NUE and economically optimum crop yield the medium application nitrogen rate seems most suitable. But the highest nitrogen application rate (N3) is not recommended because mostly of particularly low NUE and associated vulnerability of the unused by crops nitrogen for leaching or emission to the atmosphere as well as costly production.

5. Conclusions

The results obtained in this research indicate a significant influence of soil type (Gleysol and Stagnosol) and soil tillage treatment on selected soil physical properties. In both experimental years the highest soil compaction (ρ_b and PD) on average for all tillage treatments were recorded on Gleysol. The highest values of ρ_b and PD were measured in the root zone (soil layer 20–40 cm). At all depths the highest values of ρ_b and PD were recorded on DH treatment on Gleysol. In both experimental years higher soil porosity was recorded on Stagnosol comparing to Gleysol. Soil porosity decreased with the profile depth on Stagnosol. On the Gleysol reduction of porosity at a depth of 20–40 cm at all soil tillage treatments and the re-rise soil porosity at a depth of 40–60 cm was recorded. The highest values of soil porosity were recorded in soil layer 0–20 cm.

The highest winter wheat yields (with the exception of CH treatment on Gleysol) and harvest index within the conservation tillage treatments were recorded, indicating that these treatments may be the most appropriate tillage systems for Stagnosol and Gleysol. Maize yields did not differ in relation to soil tillage treatments at Stagnosol although the harvest index was the highest on conservation tillage treatments. The lowest maize yield was recorded at no till treatment at Gleysol although there were no differences between tillage treatments in the harvest indexes.

There were no limitations of nitrogen rate recommendations in the conservation soil tillage treatments compared to the CT tillage treatment, indicating that there was no need to increase nitrogen application rates when using conservation soil tillage treatments.

Soil cover crop residues decreasing in following order: NT > CH > SS > DH > CT.

Increasing the amount of nitrogen increased soil coverage for maize and winter wheat at both experimental years and experimental fields. Nitrogen use efficiency (NUE) in general decreased with increasing N application rate from N1 (30% lower than optimum recommended), N2 (optimal recommended) and N3 (30% higher than optimum). The yield increased appreciably from N1 to N2 whereas from N2 to N3 it rather decreased, increased or remained almost the same depending on the tillage system or experimental site.

The effect of conventional and conservation tillage systems on NUE and crop yield was not consistent and varied depending on particular tillage system, crop type and soil type. At majority of comparable tillage and nitrogen treatments the NUEs were higher in the more productive Gleysol soil type (Magadenovac) than the Stagnosol soil type (Cacinci). According to the results of this research the proper selection of the soil tillage system depends on soil type as well as the climate conditions during the vegetation period. The obtained results indicate the importance of optimal nitrogen fertilization and the possibility of replacement of conventional soil tillage with some conservation systems, thus reducing soil degradation and achieving high and stable yields.

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Appendix A. 1 Descriptive statistic for some selected soil compaction physical properties on experimental sites

	Gleysol (Magadenovac)									Stagnosol (Cacinci)								
	0-20 cm			20-40 cm			40-60 cm			0-20 cm			20-40 cm			40-60 cm		
	ρ_b	PD	P	ρ_b	PD	P	ρ_b	PD	P	ρ_b	PD	P	ρ_b	PD	P	ρ_b	PD	P
CT (2013 year)																		
Mean	1.52	1.68	39.08	1.63	1.80	35.30	1.58	1.79	38.07	1.48	1.74	42.45	1.55	1.81	39.94	1.58	1.84	36.73
Min	1.36	1.52	35.48	1.46	1.63	30.54	1.52	1.73	35.65	1.40	1.67	29.42	1.45	1.71	36.07	1.49	1.74	33.76
Max	1.61	1.77	45.57	1.75	1.92	42.02	1.64	1.85	40.38	1.56	1.82	45.4	1.65	1.91	43.81	1.66	1.91	40.50
CV	4.52	4.08	7.05	4.84	4.40	8.88	2.14	1.89	3.48	3.23	2.74	4.38	3.57	3.06	5.37	3.66	3.15	6.31
CT (2014 year)																		
Mean	1.53	1.70	38.43	1.53	1.69	39.43	1.59	1.79	37.79	1.39	1.65	45.83	1.47	1.73	43.06	1.56	1.82	37.44
Min	1.45	1.61	34.55	1.40	1.56	32.31	1.50	1.71	35.07	1.28	1.54	42.49	1.37	1.63	37.70	1.51	1.77	35.00
Max	1.63	1.79	41.84	1.71	1.87	44.61	1.66	1.86	41.05	1.48	1.74	50.31	1.61	1.87	46.82	1.63	1.88	39.51
CV	3.38	3.06	5.42	5.63	5.08	8.64	2.30	2.04	3.79	4.51	3.80	5.33	4.62	3.92	6.11	1.99	1.71	3.33
SS (2013 year)																		
Mean	1.51	1.68	39.32	1.64	1.81	34.74	1.59	1.80	37.73	1.50	1.76	41.63	1.52	1.78	41.13	1.55	1.80	38.13
Min	1.35	1.52	33.54	1.60	1.76	30.67	1.52	1.72	35.67	1.37	1.63	39.40	1.39	1.65	37.86	1.36	1.62	33.03
Max	1.65	1.82	45.74	1.75	1.91	36.52	1.64	1.85	40.57	1.56	1.82	46.72	1.60	1.87	46.07	1.67	1.93	45.48
CV	5.32	4.80	8.21	2.16	1.97	4.06	2.29	2.02	3.77	3.18	2.71	4.46	3.99	3.41	5.72	6.40	5.50	10.39
SS (2014 year)																		
Mean	1.53	1.69	38.62	1.61	1.77	36.21	1.60	1.80	37.38	1.41	1.67	45.08	1.46	1.72	43.39	1.60	1.85	36.01
Min	1.40	1.57	32.35	1.51	1.68	32.79	1.51	1.71	34.94	1.25	1.51	39.05	1.27	1.53	40.45	1.50	1.76	24.40
Max	1.68	1.85	43.59	1.69	1.86	39.98	1.66	1.87	40.89	1.57	1.83	51.44	1.54	1.80	50.83	1.89	2.14	39.98
CV	5.44	4.91	8.65	3.44	3.12	6.07	2.20	1.95	3.69	6.99	5.89	8.51	4.45	3.77	5.80	5.39	4.65	9.58
CH (2013 year)																		
Mean	1.48	1.65	40.45	1.60	1.76	36.58	1.58	1.79	37.96	1.51	1.77	41.26	1.50	1.76	41.77	1.60	1.85	36.14
Min	1.35	1.51	36.08	1.47	1.64	32.08	1.52	1.73	35.12	1.41	1.67	38.68	1.35	1.61	35.68	1.51	1.77	32.38
Max	1.59	1.76	45.97	1.71	1.88	41.60	1.65	1.86	40.35	1.58	1.84	45.09	1.66	1.92	47.65	1.69	1.95	39.52
CV	4.67	4.21	6.88	3.70	3.35	6.41	2.19	1.94	3.59	2.87	2.44	4.08	8.00	6.82	11.16	3.13	2.70	5.53
CH (2014 year)																		
Mean	1.51	1.67	39.44	1.63	1.79	35.37	1.60	1.80	37.37	1.39	1.65	45.98	1.47	1.73	43.20	1.57	1.82	37.23
Min	1.42	1.59	34.79	1.49	1.66	30.87	1.55	1.75	35.11	1.25	1.52	40.88	1.31	1.57	39.86	1.52	1.78	35.31
Max	1.62	1.79	42.93	1.74	1.91	40.86	1.65	1.86	39.31	1.52	1.78	51.24	1.55	1.81	49.12	1.62	1.87	39.12
CV	3.58	3.22	5.49	3.86	3.50	7.05	1.78	1.57	2.98	5.32	4.47	6.25	5.31	4.51	6.98	1.97	1.70	3.33
DH (2013 year)																		
Mean	1.54	1.70	38.32	1.63	1.80	35.30	1.58	1.78	38.21	1.51	1.77	41.39	1.48	1.74	42.58	1.56	1.81	37.61
Min	1.44	1.61	34.22	1.53	1.70	32.09	1.45	1.65	34.73	1.40	1.66	38.91	1.41	1.67	37.90	1.42	1.68	32.82
Max	1.64	1.80	42.06	1.71	1.88	39.13	1.66	1.87	43.23	1.57	1.83	45.61	1.60	1.86	45.38	1.68	1.93	43.02

CV	3.89	3.51	6.26	2.69	2.44	4.93	3.38	2.98	5.46	2.36	2.01	3.34	4.80	4.08	6.47	4.17	3.59	6.92
DH (2014 year)																		
Mean	1.54	1.70	38.27	1.66	1.83	33.94	1.58	1.79	37.86	1.38	1.64	46.47	1.47	1.73	43.00	1.58	1.84	36.70
Min	1.36	1.52	31.21	1.59	1.75	31.83	1.55	1.76	36.22	1.23	1.49	39.60	1.39	1.65	40.03	1.53	1.78	35.62
Max	1.71	1.88	45.52	1.72	1.88	36.97	1.63	1.83	39.09	1.55	1.81	52.27	1.55	1.81	46.12	1.61	1.86	38.81
CV	6.40	5.78	10.32	2.11	1.92	4.10	1.32	1.16	2.16	8.20	6.89	9.45	2.88	2.44	3.82	1.55	1.34	2.67
NT (2013 year)																		
Mean	1.49	1.66	40.01	1.63	1.79	35.48	1.55	1.75	39.33	1.50	1.76	41.54	1.48	1.74	42.58	1.57	1.83	37.12
Min	1.31	1.48	35.81	1.51	1.67	29.80	1.50	1.71	36.20	1.44	1.70	37.67	1.39	1.65	36.76	1.46	1.71	33.57
Max	1.60	1.76	47.37	1.77	1.93	40.13	1.63	1.83	41.20	1.60	1.86	44.12	1.63	1.89	46.22	1.66	1.92	41.66
CV	6.24	5.62	9.36	4.46	4.05	8.11	2.20	1.94	3.40	3.05	2.60	4.29	4.72	4.02	6.37	3.47	2.99	5.89
NT (2014 year)																		
Mean	1.56	1.73	37.20	1.66	1.83	33.95	1.58	1.79	37.85	1.39	1.65	46.08	1.45	1.71	43.82	1.54	1.80	38.25
Min	1.44	1.60	32.31	1.55	1.72	30.33	1.52	1.73	35.80	1.27	1.53	40.95	1.40	1.66	41.31	1.46	1.72	35.99
Max	1.69	1.85	42.35	1.76	1.92	38.32	1.64	1.84	40.28	1.52	1.78	50.72	1.51	1.78	45.78	1.60	1.85	41.59
CV	4.51	4.08	7.62	3.39	3.08	6.59	2.03	1.79	3.33	6.45	5.43	7.55	1.99	1.68	2.55	2.53	2.17	4.09

Note: ρ_b-bulk density, g cm^{-3}; PD-packing density, g cm^{-3}; P-total porosity, %; Mean-average data value; Min-minimum data value; Max-maximum data value; CV-coefficient of variation.

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